Pressure imbalance of FRII radio source lobes: a role of energetic proton population

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Abstract.
Recently Hardcastle & Worrall (2000) analyzed 63 FRII radio galaxies imbedded in the X-ray radiating gas in galaxy clusters and concluded, that pressures inside its lobes seem to be a factor of a few lower than in the surrounding gas. One of explanations of the existing 'blown up' radio lobes is the existence of invisible internal pressure component due to energetic cosmic ray nuclei (protons). Here we discuss a possible mechanism providing these particles in the acceleration processes acting at side boundaries of relativistic jets. The process can accelerate particles to ultra high energies with possibly a very hard spectrum. Its action provides also an additional viscous jet breaking mechanism. The work is still in progress.

I PARTICLE ACCELERATION AT THE JET BOUNDARY

For particles with sufficiently high energies the transition layer between the jet and the ambient medium can be approximated as a surface of discontinuous velocity change, a tangential discontinuity ('td'). If particles' gyroradia (or mean free paths normal to the jet boundary) are comparable to the actual thickness of this shear-layer interface it becomes an efficient cosmic ray acceleration site provided the considered velocity difference, U, is relativistic and the sufficient amount of turbulence is present in the medium. The problem was extensively discussed in early eighties by Berezhko with collaborators (see the review by Berezhko 1990) and in the diffusive limit by Earl et al. (1988) and Jokipii et al. (1989). The case of a relativistic jet velocity was considered by Ostrowski (1990, 1998, 2000). The simulations (Ostrowski 1990, cf. Bednarz & Ostrowski 1996 for shock acceleration) show that in favorable conditions the acceleration process acting at relativistic tangential discontinuity of the velocity field can be very rapid, with the time scale

$$\tau_{td} = \alpha \frac{r_g}{c} \quad , \tag{1}$$

where r_g is a particle gyroradius in the ambient medium and – for efficient particle scattering – the numerical factor α can be as small as $\sim$ 10. The introduced acceleration time is coupled to the 'acceleration length' $l_{td} \sim \alpha r_g$ due to particle advection in the jet flow. In the case of a non-relativistic jet or a small velocity gradient in the boundary shear layer the acceleration process is of the second-order in velocity and a rather slow one. Then, the ordinary second-order Fermi process in the turbulent medium can play a significant, or even a dominant role in the acceleration. The acceleration time scales can be evaluated only approximately for these processes, and - for particles residing within the considered layer - we can give an acceleration time scale estimate

$$\tau_{II} = \frac{r_g}{c} \frac{c^2}{V^2 + \left(\frac{\lambda U}{D}\right)^2} \qquad , \tag{2}$$

where V is a turbulence velocity ($\sim$ the Alfvén velocity for subsonic turbulence), λ is a mean particle free path normal to the jet axis and D is a shear layer thickness. The first term in the denominator represents the second-order Fermi process, while the second term is for the viscous cosmic ray acceleration. One expects that the first term dominates at low particle energies, while the second at larger energies, with τ_{II} approaching the value given in Eq. (1) for $\lambda \sim D$ and $U \sim c$.

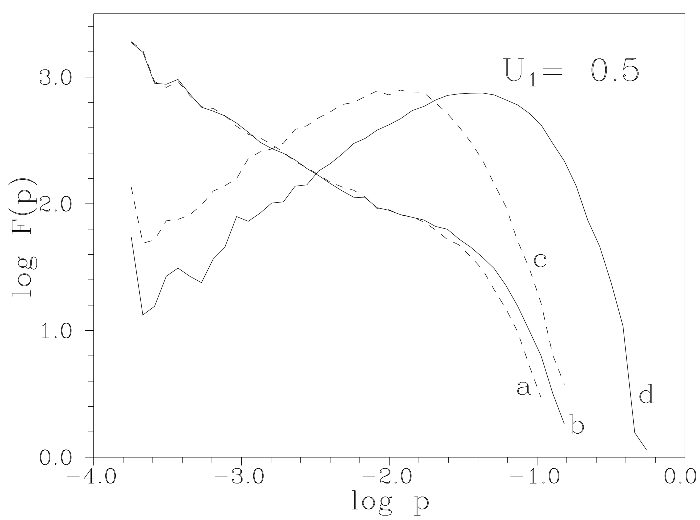

FIGURE 1. Comparison of the escaping particle spectra formed with wide (full lines 'b' and 'd') and narrow (dashed lines 'a' and 'c') turbulent cocoon surrounding the jet (cf. Ostrowski 1998). The results are presented for two possible particle injection sites: at the terminal shock (cases 'a' and 'b'), and far upstream the shock (cases 'c' and 'd'), where only the boundary acceleration is effective. Spectra of escaping particles are presented, the ones diffusively escaping from the cocoon (mostly in 'c' and 'd') and these advected downstream the terminal shock (mostly in 'a' and 'b'). Particle momentum unit is chosen in a way to give its gyroradius equal the jet radius at $p = 1$. Initial spectrum fluctuations appear near the injection momentum.

II DISCUSSION

Conditions within the large scale jets of FRII radio sources allow for acceleration of cosmic ray protons up to energies $\sim 10^{19}$ eV (e.g. Rachen & Biermann 1993, Ostrowski 1998). A characteristic feature of the boundary acceleration process in a simple considered model is formation of very flat spectrum of *escaping particles*. It is due to the on average parallel magnetic field configuration within the shear layer, limiting the low cosmic rays escape. Such particles residing within the shear layer volume can more efficiently stream to higher energies due to acting the acceleration process than to escape diffusively off the jet. At some higher energies escape becomes substantial, leading to the spectrum cut-off formation. In the considered conditions radiative losses are insignificant for protons.

Acting of the above mentioned processes can have pronounced consequences for the jet propagation if the seed particle injection at 'low energies' is efficient. Accelerated particles provide a viscous agent slowing down the jet movement. Because the jet energy is transmitted mostly to high energy nuclei, this dissipative process can occur without significant radiative effects. If a jet appearing from the central source with the Lorentz factor $\sim$ a few slows down to mildly relativistic velocities at large distances, the dissipated jet kinetic energy can be several times larger than the one available in terminal shocks. This amount is sufficient to explain additional pressure component providing stability of radio lobes against pressure of the X-ray emitting gas.

If the above interpretation is true, then some further consequences of the discussed accelerating process may arise. In particular acceleration of nuclei could be energetically inefficient in purely electron-positron jets, leading to less efficient jet breaking at large scales. Also, if the considered energetic particles escape from the radio lobes too fast, the required internal pressure component could not be sustained. A series of such problems are under study now.

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